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14. ABSTRACT

The specific objectives of this DURIP project were to provide direct measurements of velocity and currents in narrow straits with shallow sill depths in order to:-

1. Examine the relative roles of the tidal and longer timescale flows in the generation and evolution of the small-scale dynamical flow features in straits,
2. Determine how the small-scale features evolve with observed across- and along-strait variation in sea level and the corresponding strength and direction of the mean flow,
3. Identify how the small-scale flow structures and sea-level variability may be modulated by both the remote and the local forcing, particularly in response to the seasonal reversal in the monsoon winds.

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# An Ocean Sensor Array to Detect Small-Scale Variability

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## LONG-TERM GOALS

The long-term goal of this DURIP award was to develop an ocean sensor array, designed to directly measure the small-scale variability in currents and properties over the full depth of the water column. The ocean sensor array, consisting of bottom mounted Acoustic Doppler Current Profilers (ADCPs) and temperature-conductivity sensors, was deployed in the narrow straits of the Philippines as part of the ONR DRI "Characterization and Modeling of Archipelago Strait Dynamics". The goal of the DRI (known as PhilEx), is to understand the processes that control the generation, evolution and distribution of small-scale, time-dependent features within straits, and how these features interact with the large-scale sub-tidal throughflow within which they are embedded. The strong currents on the strait sills precludes the use of conventional moorings, so the bottom mounted ADCPs are the only feasible way to obtain long-term, full-depth observations of the subsurface currents in these dynamic environments. The ADCP moored time series will be used to understand the relative roles of the tidal signal within the straits, as well as the large-scale currents that may flow from the boundaries through the archipelago, in generating and maintaining the major flow features within the straits. Ultimately, this will enable a better representation and prediction in numerical and theoretical models of the structure and evolution of the small-scale features common to sea straits, including their time-dependent variability.

## OBJECTIVES

The specific objectives are to provide direct measurements of velocity and currents in narrow straits with shallow sill depths in order to:-
1. Examine the relative roles of the tidal and longer timescale flows in the generation and evolution of the small-scale dynamical flow features in straits,
2. Determine how the small-scale features evolve with observed across- and along-strait variation in sea level and the corresponding strength and direction of the mean flow,
3. Identify how the small-scale flow structures and sea-level variability may be modulated by both the remote and the local forcing, particularly in response to the seasonal reversal in the monsoon winds.

Ultimately, this will effort will provide a long-term context for the ship-borne, synoptic-type measurements undertaken during the PhilEx Intensive Observing Phases (IOPs) and furthermore, enable a better representation and prediction in numerical and theoretical models in a region that has no previous subsurface oceanographic time-series measurements.

## APPROACH

Strong tidal currents and relatively shallow sills in narrow straits lead to a variety of small-scale processes such as upwelling/downwelling, island and sidewall wakes, internal waves and other localized turbulent circulation patterns. These dynamics produce strong fluctuations in the currents and stratification that directly impact small vessel and AUV operation and induce turbulence that can modify acoustic signal propagation. The ocean sensor array was designed to directly measure this small-scale variability in currents and properties. The array consists of RD Instruments Long Ranger 75 kHz Acoustic Doppler Current Profilers that provide direct current measurements (ADCPs), Seabird SBE37SMs (conductivity and temperature) and Seabird SBE39s (temperature) with pressure options to monitor mooring motions, and additional hardware of syntactic floatation and acoustic releases that enable the deployment of these instruments. The instrumentation was designed to be deployed as a bottom-mounted mooring with the ADCPs in upward-looking mode. The moorings provide direct measurements of the velocity, temperature and salinity at sampling rates of ~ 0.5 hours and vertical scales of 10-20 m.

As part of PhilEx, the ocean sensor array was deployed within the straits of the Philippine archipelago in 2007 and recovered in March 2009. The ocean sensor array will provide temporal context for the "synoptic" shipborne flow and property measurements, as well as ground-truthing of high frequency radar and SAR images for other DoD funded researchers of PhilEx. The high-frequency time series data will also provide a test for evaluating and refining of models and their predictions that are not possible from shipborne observations alone. This will enable a better representation and prediction of the structure and evolution of the small-scale features.

## WORK COMPLETED

The ocean sensor array was constructed and assembled by engineers and marine technicians at the Scripps Institution of Oceanography (SIO) Hydraulics Laboratory, under the guidance of Senior Development Engineer Mr. Paul Harvey. All work and funding associated with this DURIP award is now complete.

The ocean sensor array of 3 bottom-mounted ADCP moorings were deployed in Panay Strait (sill depth ~ 580 m); Dipolog Strait (~480 m); and Surigao Strait (~166 m) during the PhilEx Exploratory Cruise in the Philippines Seas in June-July 2007. These moorings were recovered during the Joint US-Philippines cruise on the R/V Melville in November-December 2007. PI Sprintall and SIO Marine Engineer Spencer Kawamoto participated in this cruise. Moorings were redeployed at Panay, Dipolog and Surigao, and new moorings were deployed at Tablas and Mindoro Straits. All moorings were recovered during the Regional IOP cruise on the R/V Melville in March 2009. PI Sprintall and SIO Senior Development Engineer Paul Harvey participated in this cruise.

## RESULTS

The mooring deployments provide the first time series that measure the flow and properties in these southern Philippine straits. This rich and complex data set will be used to explore variability in the region. Preliminary results were presented at the Western Pacific Geophysics Meeting in Cairns, Australia in July 2007, and a few science results are highlighted here.

The mooring deployments in Mindoro and Panay Strait (Figure 1) showed an exceptionally vigorous benthic layer. The flow in the lower 100 m is consistently directed toward the southeast, the along channel direction, and suggests a strong spill-over of Intermediate water from the South China Sea into the Sulu Sea. In Panay Strait, the zonal flow component (Figure 1a) is maximum (~ 0.7 $ms^{-1}$) at the sea floor, whereas the meridional component (Figure 1b) is maximum (~ 0.8 $ms^{-1}$) around 50 m above the sea floor. It is likely this difference is due to bathymetric effects from the deepening of the southern channel bank rather than bottom friction effects.

During both North East monsoon periods, beginning ~September, regular monthly strong pulses of along-strait flow are evident in the lower 150 m that extend upwards in the water column to 200 m depth (Figure 1). A temperature sensor located at the depth of the ADCP at ~ 560 m shows that these strong southward pulses are associated with cooler water. The pulses play a strong role in ventilating the depths of the Sulu Sea. Previous studies have suggested that they may be related to episodic typhoon events in the South China Sea, although preliminary studies suggest that this is not the case during the PhilEx deployment period. The time scale and their regularity suggest a monsoonal relationship. This relationship will be further explored in the coming analysis year.

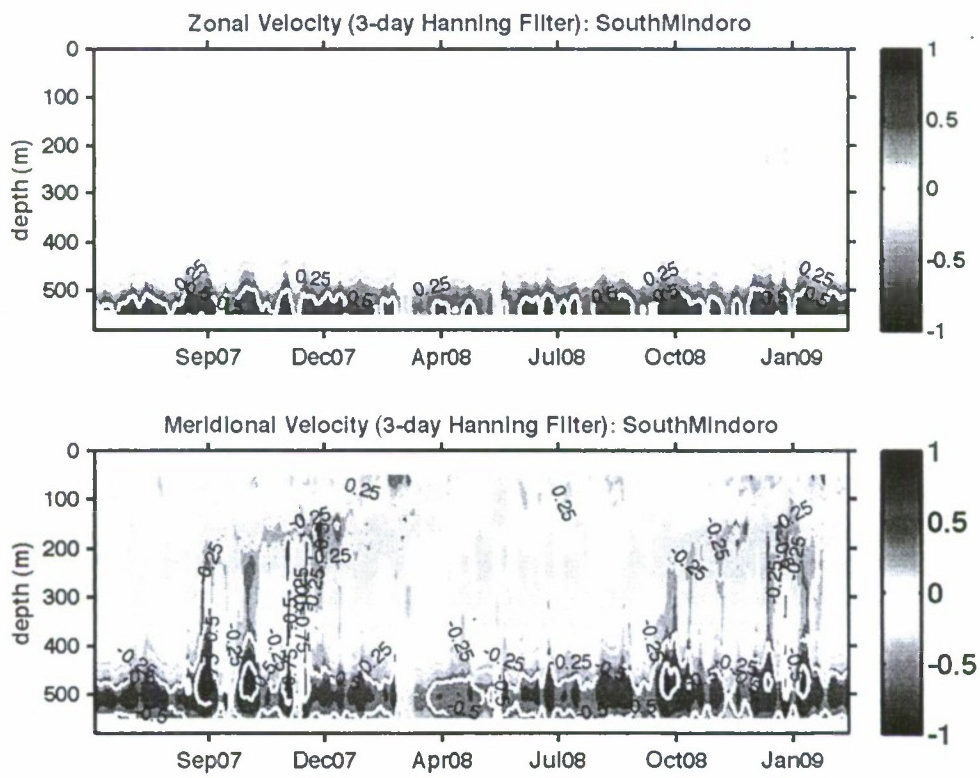


Figure 1: Zonal (top) and meridional (bottom) velocity from the mooring deployment in Panay Strait (also known as South Mindoro). Note the strong benthic layer flow, and the strong flow below 200 m during both northeast monsoon periods.

## IMPACT/APPLICATIONS

The high-resolution time series data can be used to test the veracity of numerical models of the Philippine region, with obvious application to other archipelago straits characterized by small-scale processes. Typically many of the available models resolve the narrow straits with only a few grid points, thus providing little spatial information about the internal dynamics and local complexities that occur on short time scales. The high-frequency time series observations will provide a test for evaluation and refinement of all models and their predictions that are not possible from shipborne observations alone. This will enable better representation and prediction of the structure and evolution of the small-scale features such as internal waves, sidewall eddies and separation of filaments, including their time-dependent variability in a region that has few previous subsurface oceanographic measurements.

All equipment purchased under this DURIP award will be placed in the SIO Hydraulics Laboratory Equipment Pool for access by all SIO personnel after the DRI Philippines deployment. Through this mechanism, the equipment offers the distinct potential for the enhancement of other field programs by all researchers and their students at SIO. Finally, the instrumentation funded as part of this DURIP may also open up new research capabilities: improved accuracy and resolution of currents and acoustical backscatter and the ability to make these sophisticated measurements in the surface mixed layer, bottom boundary layer and interfacial layers.

## RELATED PROJECTS

ONR award N00014-06-1-0690 was funded to support the field work and analyze the ocean sensor array data, deployed as part of the ONR DRI "Characterization and Modeling of Archipelago Strait Dynamics". An expansion proposal (N00014-06-1-0690, Modification Number P00003) entitled "A pressure gauge array for observing sea level variability within the Philippines Seas" was funded in April 2007 in order to fulfill the need to expand the pressure gauge array within the Philippines Seas as directed by the DRI.